Aspects of the Biology and Ecology of the Australian Freshwater Crayfish, *Euastacus urospinosus* (Decapoda: Parastacidae)

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The range of the upland freshwater crayfish, Euastacus urospinosus, has been extended to the Conondale Ranges (southeastern Queensland) where it occurs in creeks as well as bank burrows in rainforest at 450–550 m altitude. During sampling and trapping from 1982–1994 a total of 685 individuals were examined and aspects of reproduction, population structure, growth and habitat usage investigated.

Breeding females range from 33.8–51.8 mm ocular carapace length (OCL), appear to breed annually, carry a mean of 51 (3–119) eggs and average 31 (3–93) young. Mating apparently commences in April with males moving considerable distances (>20 m) to burrows housing mature females to pair with them. Eggs are laid about May or June, incubated for four to five months, hatch in late October or November and young released in December in the creeks. Adults only live in bank burrows and immature individuals occur predominantly in the creek. The mean OCL for crayfish in the creeks is 11.2 mm (n = 492) and 30.3 mm (n = 162) in bank burrows. The smallest free-living individual had an OCL of 5.5 mm and the largest, a male, measured 54.1 mm OCL and weighed 84.5 grams. It is estimated that females take approximately six years to reach breeding size.

A simple trapping method using black plastic tubing inserted at entrances, enabled regular capture of crays in burrows. The resulting mark-recapture program has shown that burrows are normally only occupied by one individual, except during mating in April; however, trapping success is correlated with water temperature, with least success in winter. OCL has also been demonstrated to increase with burrow entrance diameter.

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KEYWORDS: breeding seasonality, burrows, *Euastacus urospinosus*, growth, maturation, population structure, reproduction, trapping .

INTRODUCTION

There has been no detailed account of any aspect of the biology and ecology of the Australian crayfish *Euastacus urospinosus* since its description by Riek (1956), and, prior to these studies, no mature females had been collected (Morgan 1988, 1991). Morgan (1988) provided a comprehensive morphological description of the species, and the maximum ocular carapace length (OCL) of specimens examined was 36.7 mm. Morgan (1988) reported that *E. urospinosus* was restricted to tributaries of Obi Obi Creek in the Mary River Drainage Basin between Maleny and Mapleton in south-eastern Queensland, where it was found in sub-tropical rainforest above an altitude of 240 m; however, Morgan (1989) believed that the distribution of *E. urospinosus* might also extend to the Conondale Ranges.

The studies reported here originated as part of a broader research program on the impacts of forestry on water quality and aquatic faunas. The area under investigation was state forest until incorporated into the Conondale National Park in 1995. Gold prospecting and mining had occurred along the creeks and selective logging has taken place in

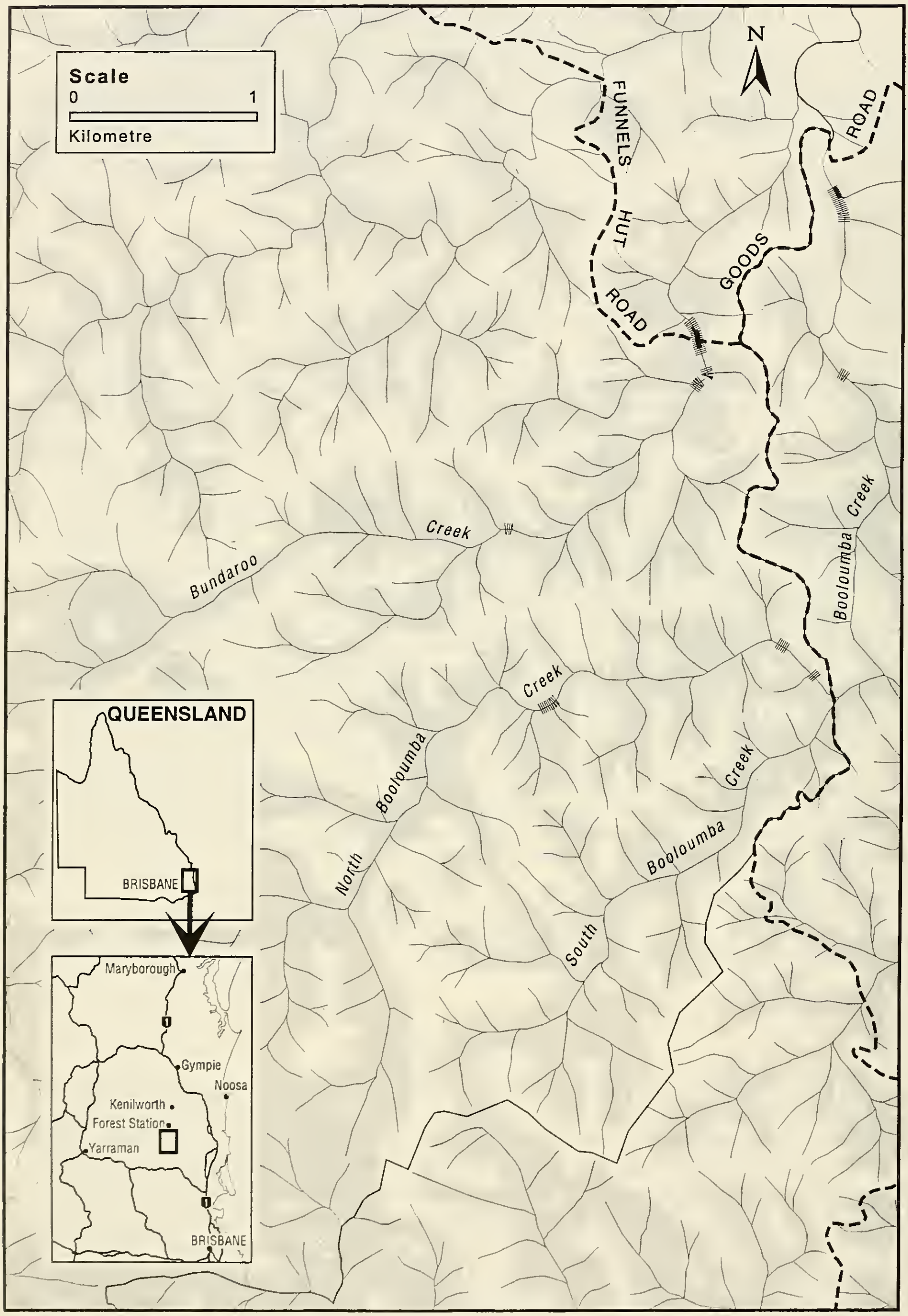


Figure 1. E. urospinosus study area.
Key to symbols: mark recapture site, creek section sampled, and rainforest.

the Booloumba and North Booloumba Creek catchments. The Bundaroo Creek catchment has no history of logging, although cedar-cutters may have taken some timber earlier this century.

Aside from verifying the suspected extended range of *E. urospinsosus* and documenting major habitat parameters, this paper has the following objectives: to investigate reproductive maturation, fecundity and seasonality; to report on population structure as well as growth; and to describe habitat usage.

MATERIALS AND METHODS

Study Area

The study area lies in the Conondale Ranges NNW of Brisbane at approximately 26°42′S, 152°36′E. Crayfish were studied on Booloumba Creek and its tributaries North Booloumba Creek and Bundaroo Creek at 450–550 m altitude. Booloumba Creek drains to the Mary River. Mark-recapture studies were conducted at two sites, one each on Booloumba Creek and Bundaroo Creek (Fig. 1). Data for instream crayfish were collected at various sites on Booloumba Creek or its tributaries, and include opportunistic records from sites where *Euastacus hystricosus* was under study (Smith et al. 1998). *E. hystricosus* is sympatric with *E. urospinosus* in this area.

Booloumba Creek and its tributaries can be broadly described as permanent, montane, rocky watercourses with slow basal flows. During periods of basal flow the creeks consist of a series of pools interconnected by glides, runs or riffles. Usually pools are less than 1.2 m deep and 30 m in length, occasionally there are larger and deeper pools (≤150 m long: ≤3.0 m depth). Some sections are dominated by larger rocks and boulders, with occasional sections where the flow is over exposed bedrock with cascades or waterfalls when the gradient is steeper. Pool width varies but is generally less than 10 m and rarely over 20 m. Substrates in the larger pools are usually a mosaic of slopes, flats and bars of gravel, stones and rocks, large loose rocks, boulders, logs and accumulations of decaying organic matter. These lie on either bedrock or a bed of gravel, stones and rocks. Riffles, runs and glides generally have substrates of loose rocks and stones lying on a bed of gravel, rocks and stones.

Vegetation within the study area is mainly rainforest and wet sclerophyll forest, with or without eucalypt emergents. The upper tree storey includes *Archontophoenix cunninghamiana* (Piccabeen Palm), *Argyrodendron actinophyllum* (Tulip Oak), *A. trifoliatum* (Booyong), *Auracaria bidwillii* (Bunya Pine), *Caldcluria paniculosa* (Rose-leaf Marara), *Castanospermum australe* (Black Bean), *Diopyrus pentamera* (Black Myrtle), *Eleocarpus grandis* (Blue Quandong), *Ficus watkinsiana* (Strangler Fig), *Gmelina leichardtii* (White Beech), *Lophostemon confertus* (Brush Box), *Planchonella australis* (Black Plum), *Sloanea woollsii* (Yellow Carabeen) and *Syzigium* spp. Emergents were mainly *Eucalyptus grandis* (Flooded Gum) in gullies, while on upper slopes and ridges *E. gummifera* (Red Stringybark) and *E. microcorys* (Tallowood) were the main emergents.

Rainforest dominates along the creeks and in places the palm, *Archontophoenix cunninghamiana,* forms stands with little ground vegetation. Vegetation on the creek verges is sparse where there are large expanses of exposed bedrock. Ground cover can be dominated by tufted clumps of mat rush, *Lomandra longifolia,* wherever boulders dominate a broader floodplain and channel. The exotic weeds *Lantana camara* (Lantana) and *Eupatorium riparium* (Mist Flower) are also present.

Temperatures

Temperatures were monitored at both mark-recapture sites using maximum-minimum thermometers. In Bundaroo Creek readings were taken in shallow, moving water in a well shaded riffle; in Booloumba Creek measurements were taken in shallow, well shaded moving water at the confluence of a riffle with a pool/glide. Ground water temperatures were estimated by burying screw-top 4 litre plastic containers of water each with a thermometer inside, with the top of the container about 0.2 m underground. Readings were taken by digging down to the top of the container, unscrewing the lid, and then, with minimal handling, reading and resetting the thermometer while keeping it under water. The lid was re-screwed and the top of the container again covered with soil and leaf litter.

Measurement, Trapping, Marking and Sampling

Size of captured individuals was determined by the ocular carapace length (OCL), measured from the posterior orbit margin to the dorsal posterior carapace margin, using dial vernier callipers (nearest 0.1 mm). Weights in the field were taken (nearest 0.25 g) using a Pesola spring balance.

In preliminary field surveys it was observed that *E. urospinosus* would often sit just inside the burrow entrance at night or late in the day. To take advantage of this behaviour a section of flexible black plastic tubing (~ 0.40–0.45 m long), of a diameter similar to the entrance, was pushed 30–50 mm into the burrow and bent flat to the ground using a rock on site. This tubing was left permanently in place during the mark-recapture study and was quickly accepted by crays as part of the burrow system. Individuals continued to sit just inside their 'extended' burrow and were captured by pulling the tubing from the burrow at night. After examination, measurement and tagging if required, crayfish were released into their burrow and the tubing re-inserted. Individuals caught in the mark-recapture study were tagged using notching pliers by cutting one or more small v-shaped notches in either the telson and/or uropods. Although the notches grew over, marks were always clearly discernible after one moult and still discernible enough after two moults to identify the individual. Moult occurrence was recorded and where possible marked crays were re-marked after each moulting.

E. urospinosus caught in creeks were not marked, except for a few caught incidentally in a *E. hystricosus* study, but regular sampling was carried out on circular 1 m^2 plots in riffle areas of Boolumba, North Booloumba and Bundaroo Creeks. Plots were sampled by lifting and removing stones or small rocks and crays captured by hand or with a small dip net. All captives were measured, weighed and sexed where possible. After sampling, the rocks and stones were placed back into the plot and the residents released throughout the plot. Crays were also caught in the creeks by searching under stones and rocks on three bank/creek cross-section survey plots, one on Booloumba Creek, two on Bundaroo Creek. All burrows in the three cross-sectional survey plots were excavated as well as a small number of burrows from the mark-recapture study.

RESULTS

This extended sampling program has confirmed the presence of substantial resident populations of *E. urospinosus* in the Conondale Ranges. During the period December 1982 to July 1994 some 685 individuals were captured and examined in the study area (Fig. 1). A total of 956 records were generated as some crays were caught more than once in the mark-recapture study.

Reproduction

All females (n = 143) below 33.2 mm OCL had flat, non-inflated gonopores; whereas 48 females ≥33.2 mm OCL had inflated gonopores and 21 carried eggs or juveniles. The smallest female with eggs or young was 33.8 mm OCL and 18.0 grams, the largest

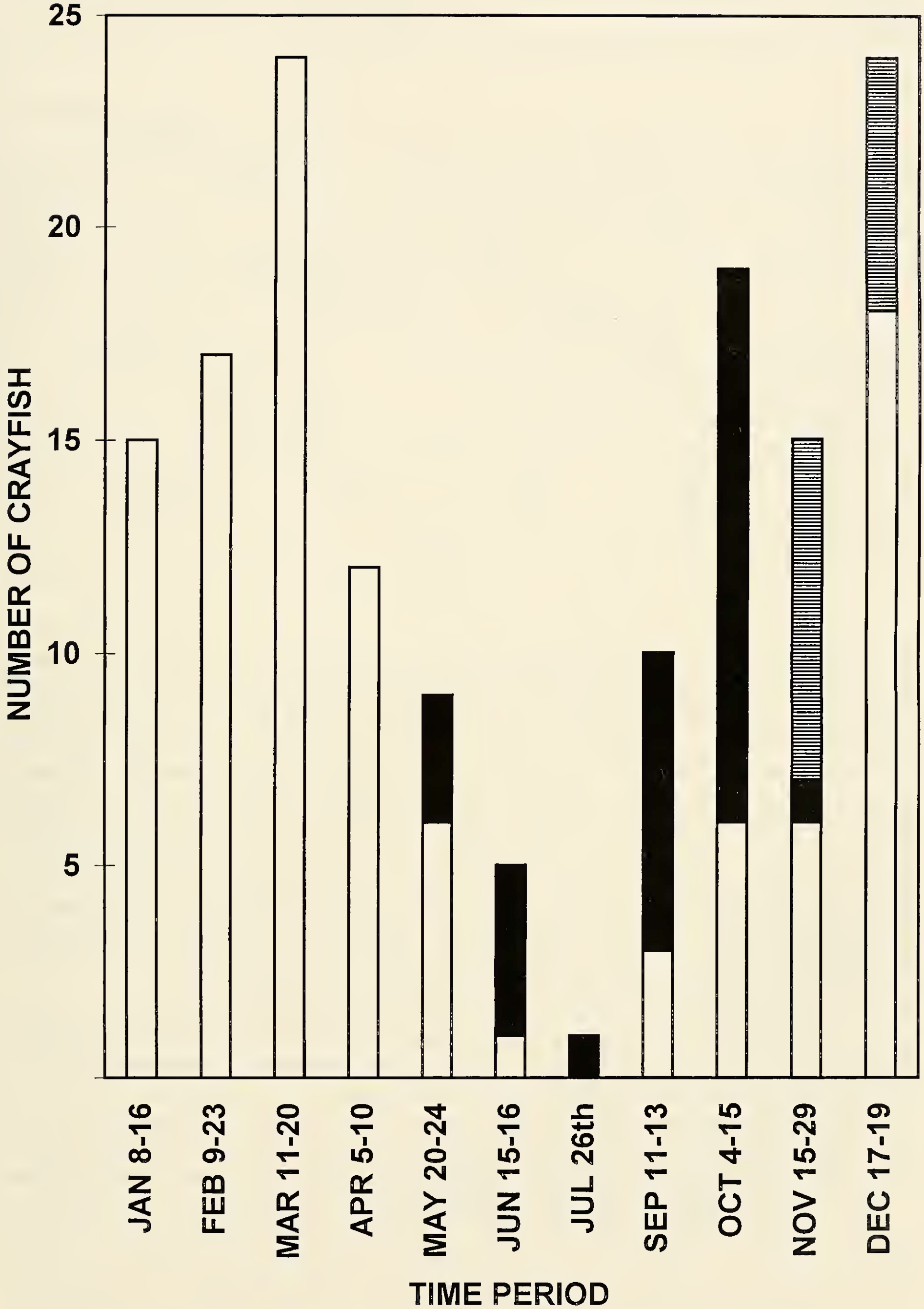


Figure 2. Reproductive status of mature *E. urospinosus* females (⩾33.8 mm OCL or with swollen gonopores). Key to symbols: ⊟ individuals carrying larvae or juveniles; ■ individuals carrying eggs (in berry); ❑ individuals not in berry.

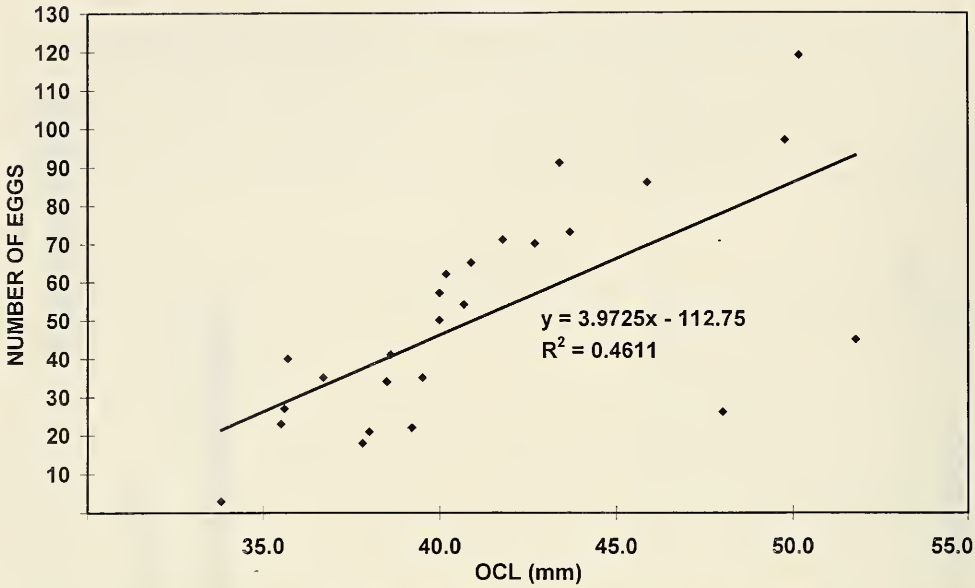


Figure 3. The relationship between OCL and numbers of eggs carried by *E. urospinosus* females.

recorded female was 51.8 mm OCL (63 g). It appears inflation of the gonopores correlates strongly with maturation. Mature females were only found in bank burrows and not in the creeks. Figure 2 graphically presents the yearly reproductive status of mature females. The data indicate that *E. urospinosus* is a winter brooder with a fixed annual cycle and a single synchronised release of juveniles in December, but the trigger for release is unknown. The earliest captures of females carrying eggs were late May (n = 3) and mid-June (n = 4). Egg incubation is 4–5 months. By the later half of November 86% of breeding females (n = 7) were carrying juveniles. No mature females were carrying eggs from 17 December to 10 April (n = 91), or eggs/juveniles from 8 January to 10 April (n = 67). All females caught over either two consecutive breeding seasons (n = 5) or three consecutive breeding seasons (n = 2), were carrying eggs or juveniles in each season; but not all mature females bred successfully each year. About one third of mature females recorded from late July to late November were not carrying eggs or juveniles.

The mean number of eggs carried by females when first captured during a breeding season was 51 (n = 25; range 3–119). The linear regression between OCL and the number of eggs carried is illustrated in Fig. 3; the larger the female the greater the number of eggs. The mean number of juveniles carried in November is 31 (n = 7; range 3–93).

In the mark-recapture study one female was monitored occupying the same burrow system for a 22 month period (Sept. 1984 to May 1986) and for the three breeding periods covered was carrying 71, 70 and 73 eggs respectively. In the second breeding season the female was not carrying eggs on 11 March, but when recaptured on 9 October had moulted and was in berry. In the interim period a mature male (37.6 mm OCL) had been captured (30 April) in the female's burrow. It had moved from a burrow 23 m away in which it had been captured on 10 April; this male was never recaptured or seen again in the female's burrow. The following year the female was not carrying eggs on 19 March, but on 20 May it had moulted and was carrying eggs again. During the intervening period a different mature male (47.7 mm OCL) had been captured in the burrow (22 April). On 20 May the female's burrow was dug out and only the female was found in the burrow system. Prior to capture in the female's burrow in April this male had been caught on 20 March in a burrow 5.75 m away. These observations suggest that a mature male will pair and mate with a mature female in her burrow system around April of each year.

Population Structure and Growth

The smallest free-living *E. urospinosus* had an OCL of 5.5 mm, the largest female recorded was 51.8 mm OCL (63.5 g) and the largest male was 54.1 mm OCL and 84.5 grams. At sites shown (Fig. 1) crays were caught in the creeks at $\leq$0.5 m depth under stones, rocks and logs in riffles, runs, glides and the shallow reaches of pools; larger individuals often had a shallow burrow system under rocks. Crays in the creek were generally small (11.2 mm mean OCL: n = 492, SD = 4.87), ranging from 5.5 mm OCL to a female of 29.7 mm OCL (14.2 g); the largest male was 26.3 mm OCL (8.4 g).

E. urospinosus also lived in burrows in the creek banks. Burrows were found up to 6 m from the basal flow water mark, especially where banks had a broader lower bench with or without flood bars of gravel, stones and rocks. There was often a concentration of burrows where the lower bank bench ended in a sharp rise. Mean OCL of bank burrow populations was 30.3 mm OCL (range 11.9–54.1 mm; n = 162; SD = 9.36). The ratio of males to females for crays captured in burrows was 1:1.16 (n = 162), and was not significantly different from 1:1 (χ^2 = 0.88; d.f. = 1; p >0.1). The mean OCL of crays in the creek was highly significantly different (p <0.001) to the mean OCL for crays living in burrows in the banks adjacent to the creek. The Mann-Whitney U test was used for this analysis as the variances were not homogeneous.

Size distribution of pooled OCL data for *E. urospinosus* caught in three creeks during this study were plotted as bi-monthly frequency histograms (Fig. 4). The size classes in the December–January period of newly released juveniles were clearly distinct from one year old crays (Fig. 4a), but the separation between one and two year olds in that period is not distinct, and even less so for three year olds, as the sample of individuals over 16 mm OCL is low. Subsequent bi-monthly plots (Fig.4 b–f), indicate that individuals between 11.0 and 16.8 mm OCL (in December–January) were probably one year old. This suggested that *E. urospinosus* had a mean OCL of 13.7 (n = 18) at 12 months of age; at two years individuals were ~ 18–19 mm OCL, and three year old individuals were ~ 22–24 mm OCL.

From these size/abundance values and moult frequency data, from mark-recapture individuals, it was possible to infer an age at which females reached maturity. Individuals with an OCL 24.1–30.8 mm (n = 7) moulted twice per year, but there was a transition from twice to once yearly moulting for crays from 30.8–33.6 mm OCL (n = 8). All larger individuals ($\geq$33.7 mm OCL), where yearly moult data were available (n = 27), moulted once per year. To determine an age for female maturity, moult increments for crays $\geq$22.4 mm OCL were plotted as a percentage of pre-moult OCL (Fig. 5) and the relationship which most accurately reflected the data was the exponential $y = 54.732\ e^{-0.073x}$ (R^2 = 0.684). According to this relationship an individual of 23 mm OCL would moult a further five times to reach a size of 33.2 mm OCL (size at which at which female gonopores become inflated). As crays 24.1–30.8 mm OCL moult twice a year and larger animals (30.8–33.8 OCL) moult annually, it is reasonable to suppose a female of 23.0 mm OCL and three years old, would take on average about another three years to reach maturity.

Bank Burrows

A total of 70 *E. urospinosus* (11.9–47.0 mm OCL) were dug out of bank burrows. The sample included an unsexed specimen as well as 37 females and 32 males. No more than one individual was retrieved from any burrow system. Forty-eight crays were dug out in February, 5 in April, 6 in May, 5 in June and 6 in September. All excavated burrows

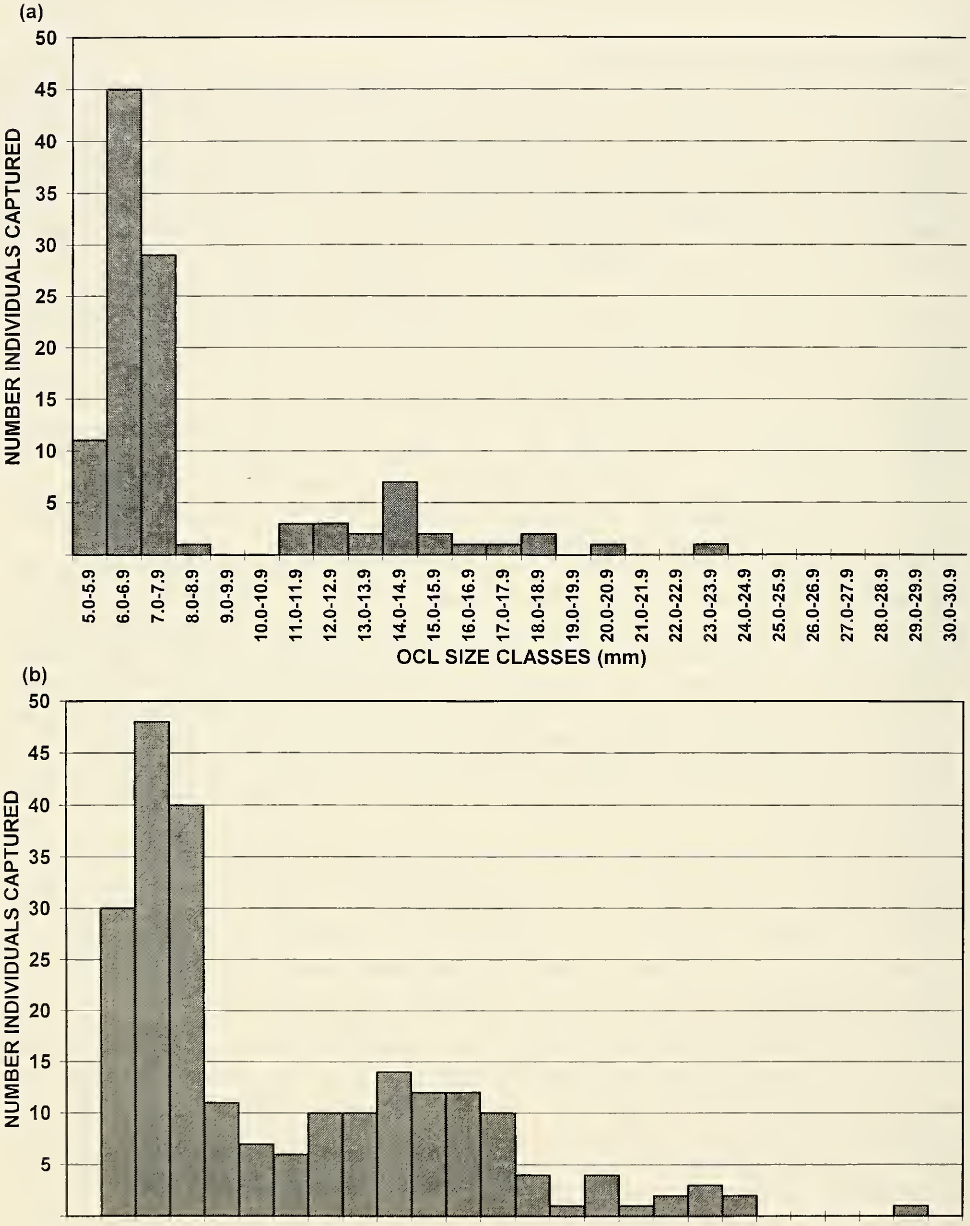


Figure 4. Pooled OCL size classes for *E. urospinosus* caught in Bundaroo, Booloumba and Nth Booloumba Creeks over 2 month intervals: (a) December and January; (b) February and March; (c) April and May; (d) June and July; (e) August and September; (f) October and November.

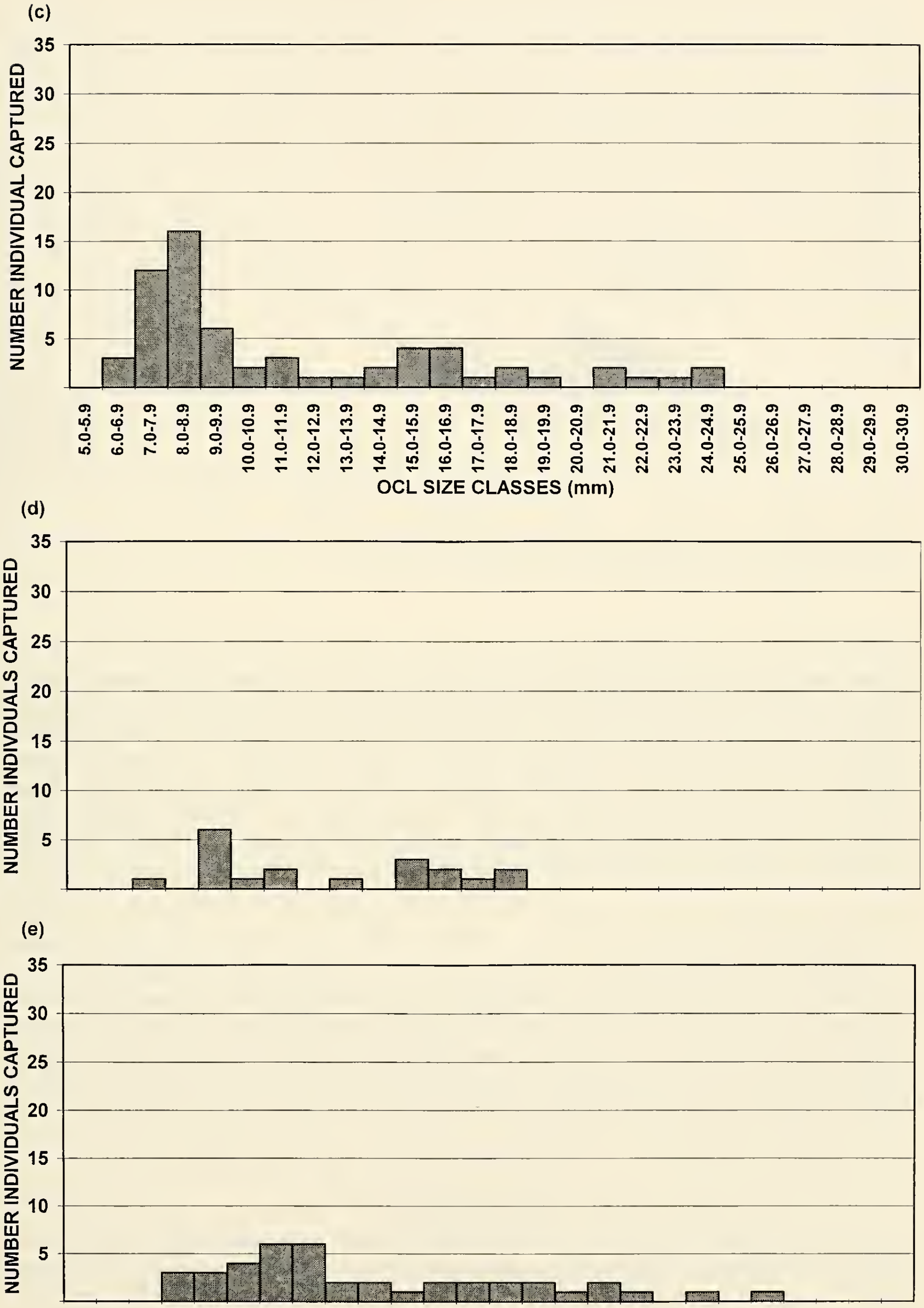


Figure 4 continued. Pooled OCL size classes for *E. urospinosus* caught in Bundaroo, Booloumba and Nth Booloumba Creeks over 2 month intervals: (c) April and May; (d) June and July; (e) August and September; (f) October and November.

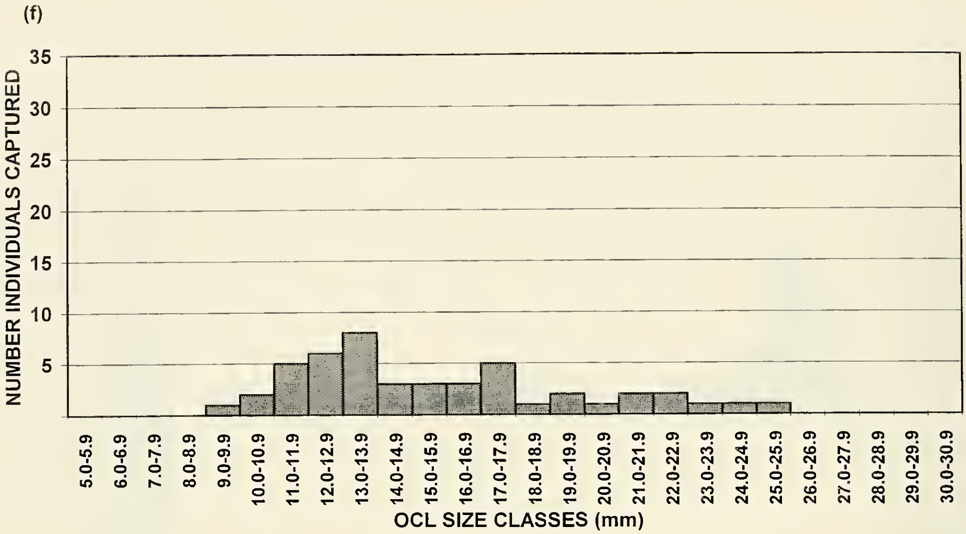


Figure 4 continued. Pooled OCL size classes for *E. urospinosus* caught in Bundaroo, Booloumba and Nth Booloumba Creeks over 2 month intervals: (f) October and November.

reached the water table and had up to three entrances; they were ≤1.3 m deep and ≤1.5 m across. Adults typically occupied burrows with one to two chambers at the bottom, one of which was always filled or partially filled with ground water. Chambers were normally 0.25–0.30 m long and 75–125 mm in diameter, but could be as long as 0.95 m. There was usually at least one blind tunnel and sometimes a closed chimney in a burrow system. Whenever an individual was caught undisturbed in a burrow system it was often sitting at the edge of, or partly in, the water in a chamber. Linear regression showed a positive relationship between OCL and burrow entrance diameter. For crays 14.7–54.1 mm OCL (n=109) the burrow diameter increased with OCL ($y = 1.0096x - 0.9416$; $R^2 = 0.741$).

Trapping and Temperature

Figure 6 summarises tube-trapping capture data and creek and groundwater temperatures at two mark-recapture sites. Creek water was below 20°C for most of the year and reached a maximum of 22.0–22.5°C. Minimum groundwater temperature (at burrow depth) in mid-winter was up to 4.5°C warmer than minimum water temperature in the creek riffle zones. Clearly *E. urospinosus* living in burrows showed little activity at their burrow entrances when creek and groundwater temperatures were at their lowest.

DISCUSSION

E. urospinosus belongs to a group of eight smaller (<55 mm OCL), poorly known Queensland *Euastacus* species, three of which in south-east Queensland are considered similar in morphology and size (Morgan 1991). *E. urospinosus* in the Conondale study area occurs mainly in rainforest where it lives in cooler waters at a higher altitude, similar to most other Queensland *Euastacus* species (Morgan 1991; Riek 1969). The maximum sizes recorded (female 51.8 mm OCL, 63.5 g : male 54.1 mm OCL, 84.5 g) during these studies make *E. urospinosus* the largest of the eight smaller, weakly spined Queensland *Euastacus*.

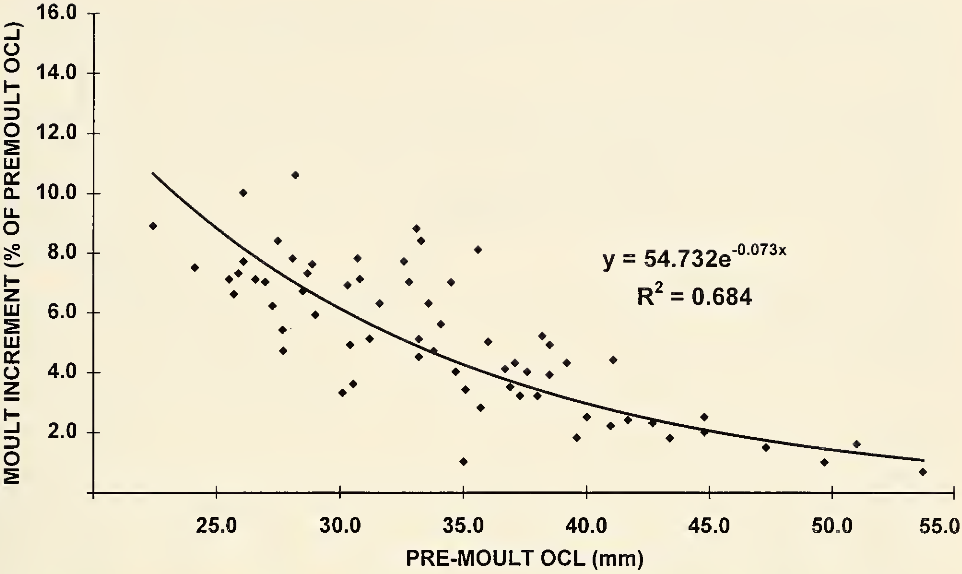


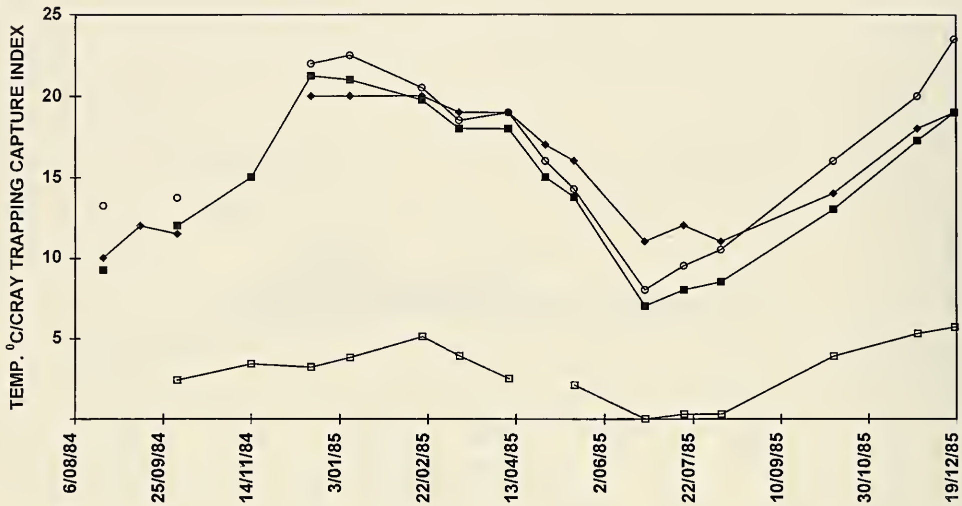
Figure 5. Relationship of moult increment (%) to pre-moult OCL in *E. urospinosus* ≥22.4 mm OCL.

Parastacid crayfish normally have either a relatively short egg incubation period during the warmer months (summer brooders), or a long incubation period over winter (winter brooders) (Honan and Mitchell 1995). This study indicates *E. urospinosus* is a winter brooder, similar to the sympatric *Euastacus hystricosus* (Borsboom, unpublished data), and a number of other *Euastacus* species listed in a reproductive review table in Turvey and Merrick (1997a). *E. urospinosus* has a lower fecundity (119) than the comparably-sized *E. australasiensis* (155), *E. keirensis* (184) and *E. yanga* (164) (Turvey and Merrick 1997a). The reason for *E. urospinosus* having a lower fecundity is unclear. It may relate to mortality levels, as breeding individuals live in burrows where they are not subject to eel predation. In addition, immature *E. urospinosus* are probably less at risk from eel predation as they rarely move about freely at night in the creek, unlike the sympatric immature *E. hystricosus*.

Breeding in *E. urospinosus* follows a fixed annual cycle with a single synchronised release of juveniles in December. It is suggested that some unknown environmental variable(s) triggers a female in December to leave its burrow, move to the creek, release young then return to its burrow. In support of this hypothesis, no free-living juveniles have been found in the burrows of mature females that have been excavated, or captured sharing a mature female's burrow. Additional supportive anecdotal observations follow. In mid-December 1983 a female carrying several release-size juveniles was caught at night in rain moving freely along Bundaroo Creek at the edge of the basal flow. This individual was approximately 1.2 m from any burrow entrance, which is the furthest any adult was observed away from a burrow entrance. The only other records of crays away from a burrow entrance were two separate instances of individuals feeding in leaf litter approximately 0.5 m and 0.6 m from burrow entrances.

Although triggers for mating, egg laying and release of juveniles are unknown in *E. urospinosus*, water temperature and photoperiod cycles have been suggested for other species (Aiken 1969; Turvey and Merrick 1997a); however, Honan and Mitchell (1995) believe control of the reproductive cycle may involve more than one periodic environ-

(a)



(b)

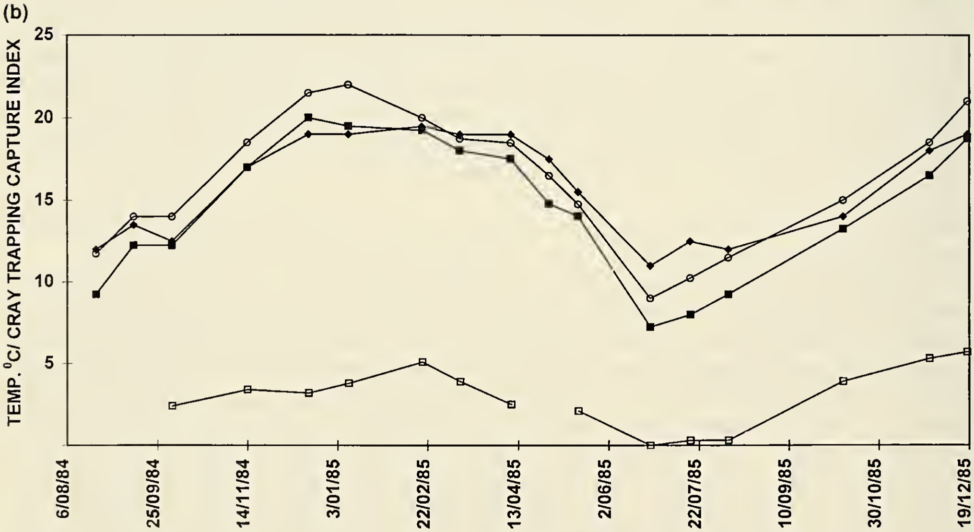


Figure 6. Minimum groundwater temperature and riffle zone minimum and maximum water temperatures for *E. urospinosus* trapping sites compared with the crayfish tube-trapping capture index: (a) Booloumba Creek; (b) Bundaroo Creek. Key to symbols: ◆ = groundwater temperature (min); ■ = riffle water temperature (min); ❍ = riffle water temperature (max); ❑ = trapping capture index.

mental variable. Rain, high humidity and/or a rise in stream levels may be important components of the triggering mechanism for the synchronised release of juvenile *E. urospinosus* in December.

It has been estimated that female *E. urospinosus* take approximately 6 years to reach reproductive maturity, but there is no information on how long other comparably-sized *Euastacus* take to reach maturity. *E. armatus, E. bispinosus* and *E. spinifer* which grow considerably larger, take 6–9, 8–11 and 5–6 years respectively (Turvey and Merrick 1997d). So for a crayfish of this size (up to 84.5 g), six years is a long maturation period; similar sized *Cherax destructor*, can commence reproducing in less than a year (Merrick 1993).

The type of partitioning suggested in *E. urospinosus* populations, where adults live in bank burrows and immature individuals in the creeks, is supported by the absence of adult captures in shallow and deep pools where *E. hystricosus* trapping was undertaken, and by the lack of observations of *E. urospinosus* adults in the creeks to depths <2.5 m, although field inspections occurred at all times of the day over many years.

This form of population segregation (adults in creek bank burrows and juveniles in creeks) has not been reported to date in any other *Euastacus* species. In the larger species *E. armatus, E. bispinosus* and *E. spinifer*, adults live and feed in watercourses (Hogger 1988; Honan and Mitchell 1995; Morgan 1986; Turvey and Merrick 1997b, c). *E. jagara, E. monteithorum* and *E. setosus,* which are similar in morphology and size to *E. urospinosus* (Morgan 1991), also construct bank burrows (Borsboom, unpublished data). Whether they too have adults living permanently in bank burrows requires further investigation.

E. urospinosus burrows can be classed as Type 2 *sensu* Horwitz and Richardson (1988), but the capture of individuals in this burrow type by tube-trapping could have wider application. This technique allows the regular recapture of burrowing crayfish with minimal stress and no disturbance of burrows or habitat, and has potential for many other cray species.

ACKNOWLEDGEMENTS

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